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Croghan et al.

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(54) **SYSTEMS AND METHODS FOR IMPROVING OUTPUT SIGNALS FROM AUDITORY PROSTHESES**

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H04R 25/00 (2006.01)

(52) **U.S. Cl.**
CPC ***H04R 25/456*** (2013.01); ***H04R 25/305*** (2013.01); ***H04R 25/453*** (2013.01); ***H04R 25/505*** (2013.01); ***H04R 25/65*** (2013.01)

(58) **Field of Classification Search**
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USPC 381/60, 23.1
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,512,834	B1	1/2003	Banter et al.
6,932,187	B2	8/2005	Banter et al.
7,065,224	B2	6/2006	Cornelius et al.
7,415,121	B2	8/2008	Mogelin et al.
7,580,537	B2	8/2009	Urso et al.
7,756,285	B2	7/2010	Sjursen et al.
8,091,680	B2	1/2012	Killion et al.
8,111,852	B2	2/2012	Ho et al.

(Continued)

FOREIGN PATENT DOCUMENTS

WO	2011033136	A2	3/2011
WO	2014107734	A2	7/2014

OTHER PUBLICATIONS

Chasin, Marshall, "Amplification fit for music lovers", The Hearing Journal, Sep. 2010, vol. 63, pp. 27-30.

(Continued)

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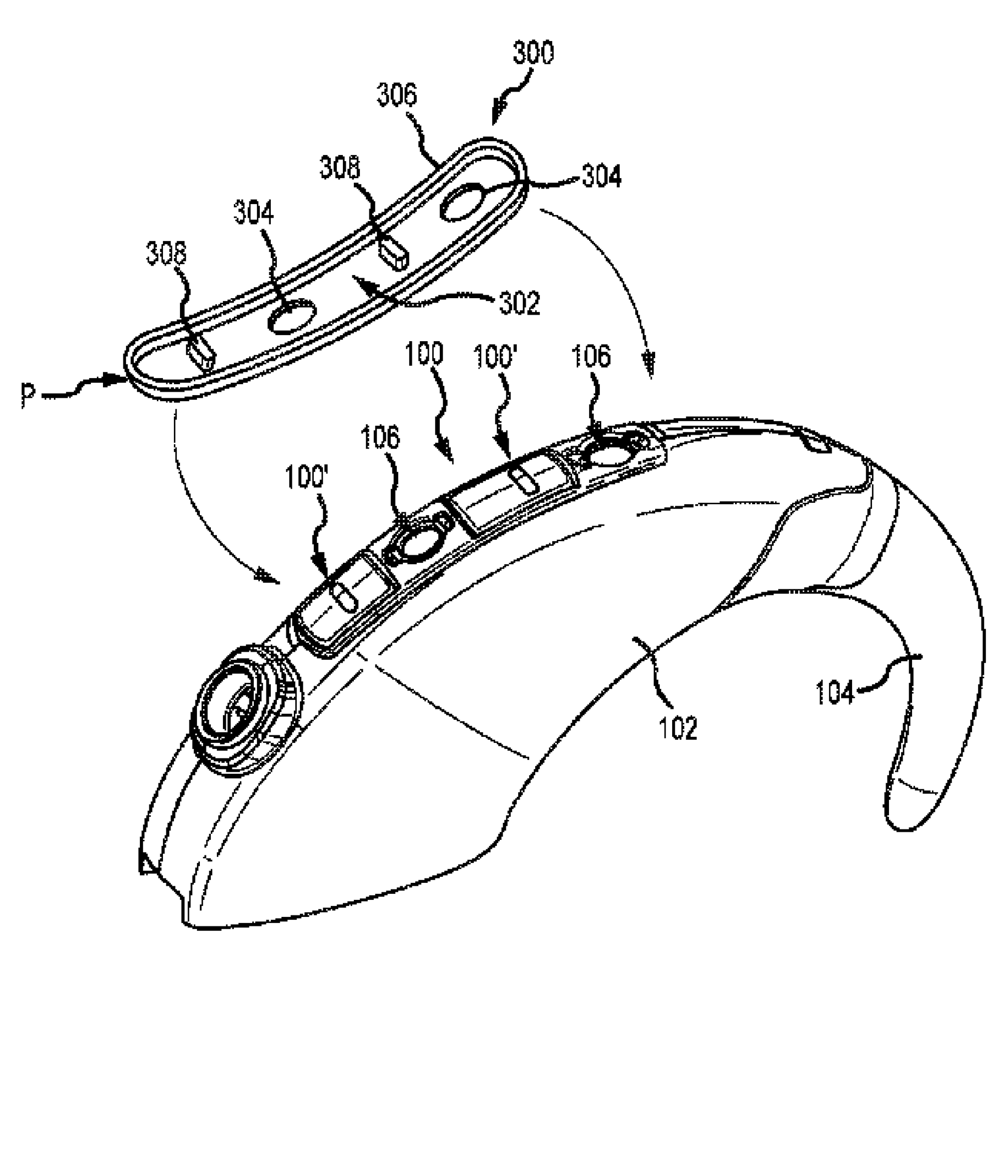
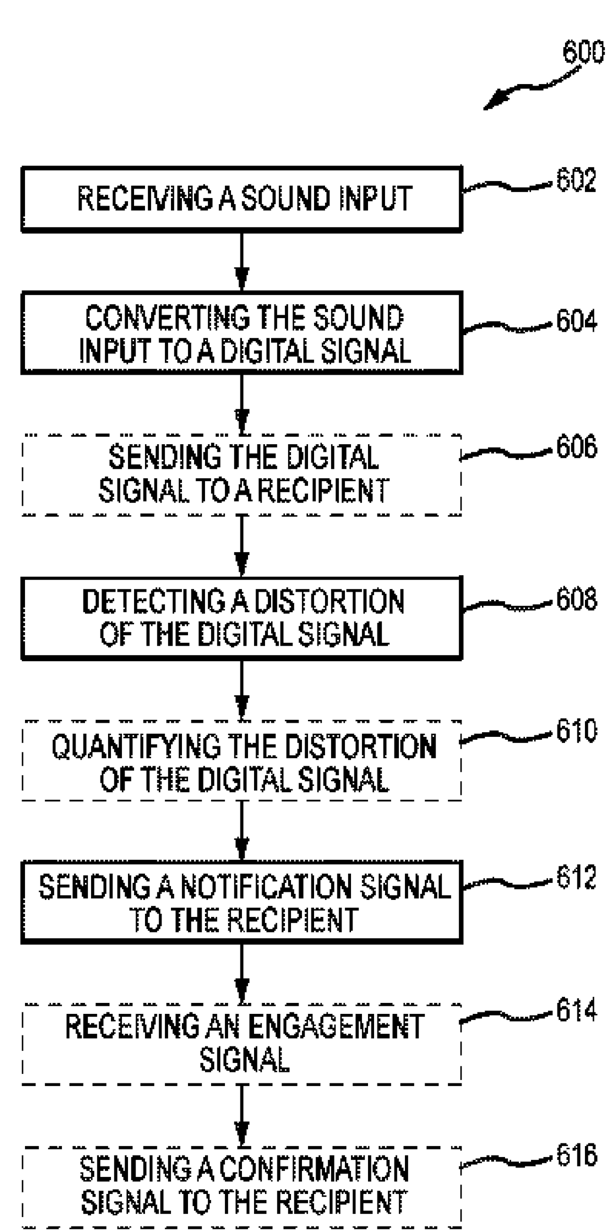
(57) **ABSTRACT**

Attenuation covers are used to reduce the amplitude of input signals at a microphone or other sound-receiving component of an auditory prosthesis. The auditory prosthesis detects distortion present in the output signal from sound processing components and notifies a recipient that an attenuation cover is recommended or desirable. Use of the cover can provide a clearer output signal to the recipient, so as to improve the recipient experience. Such covers can be particularly useful in environments where the input sound signals exceed the dynamic range of the auditory prosthesis.

20 Claims, 14 Drawing Sheets





(56) **References Cited**

U.S. PATENT DOCUMENTS

8,340,323	B2 *	12/2012	Asada	H04R 1/1041 381/103
8,739,926	B1	6/2014	Mori	
2010/0208927	A1	8/2010	Ritter et al.	
2013/0077808	A1	3/2013	Bashkaran et al.	
2013/0108097	A1	5/2013	Neilson et al.	
2014/0091406	A1	4/2014	Harney et al.	
2014/0376761	A1	12/2014	Godfrey	

OTHER PUBLICATIONS

Chasin, Marshall & Russo, Frank A., "Hearing aids and music", Trends in Amplification, 2004, vol. 8,No. 2, pp. 35-47.

Hockley, Neil S. et al., "Analog-to-digital conversion to accommodate the dynamics of live music in hearing instruments", 2012, Trends in Amplification, vol. 16, No. 3, pp. 146-158.

* cited by examiner

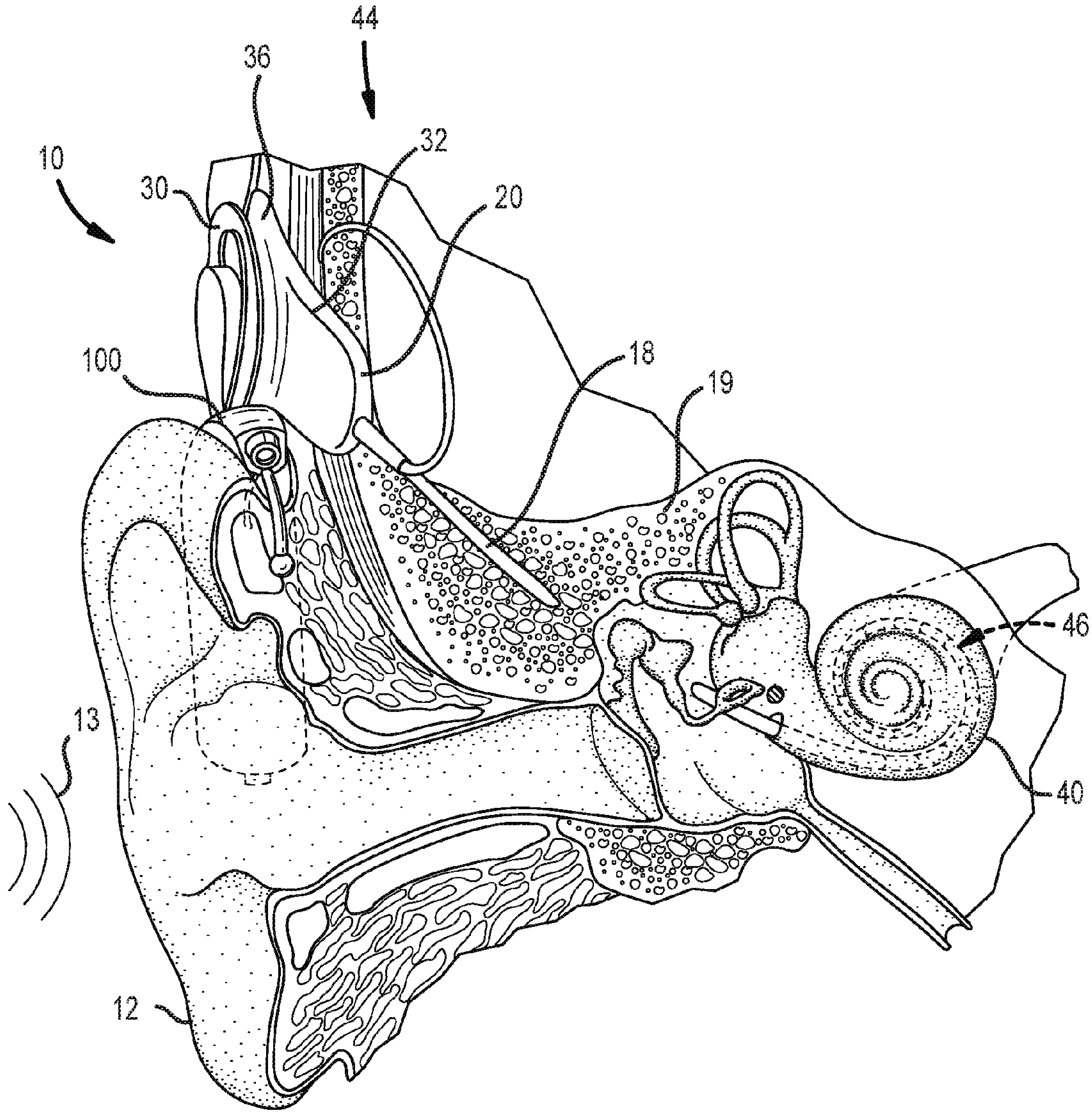


FIG.1

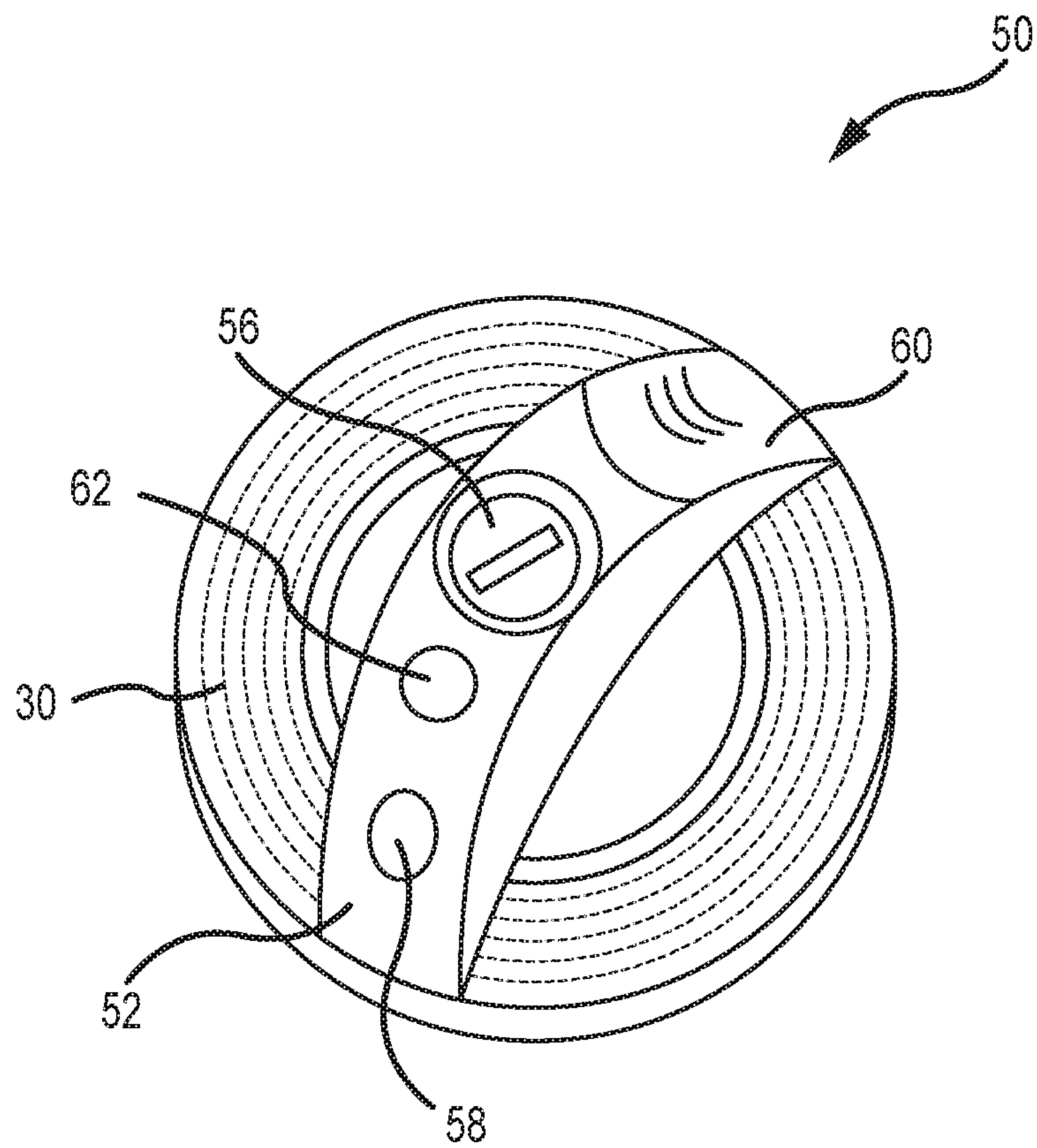


FIG.1A

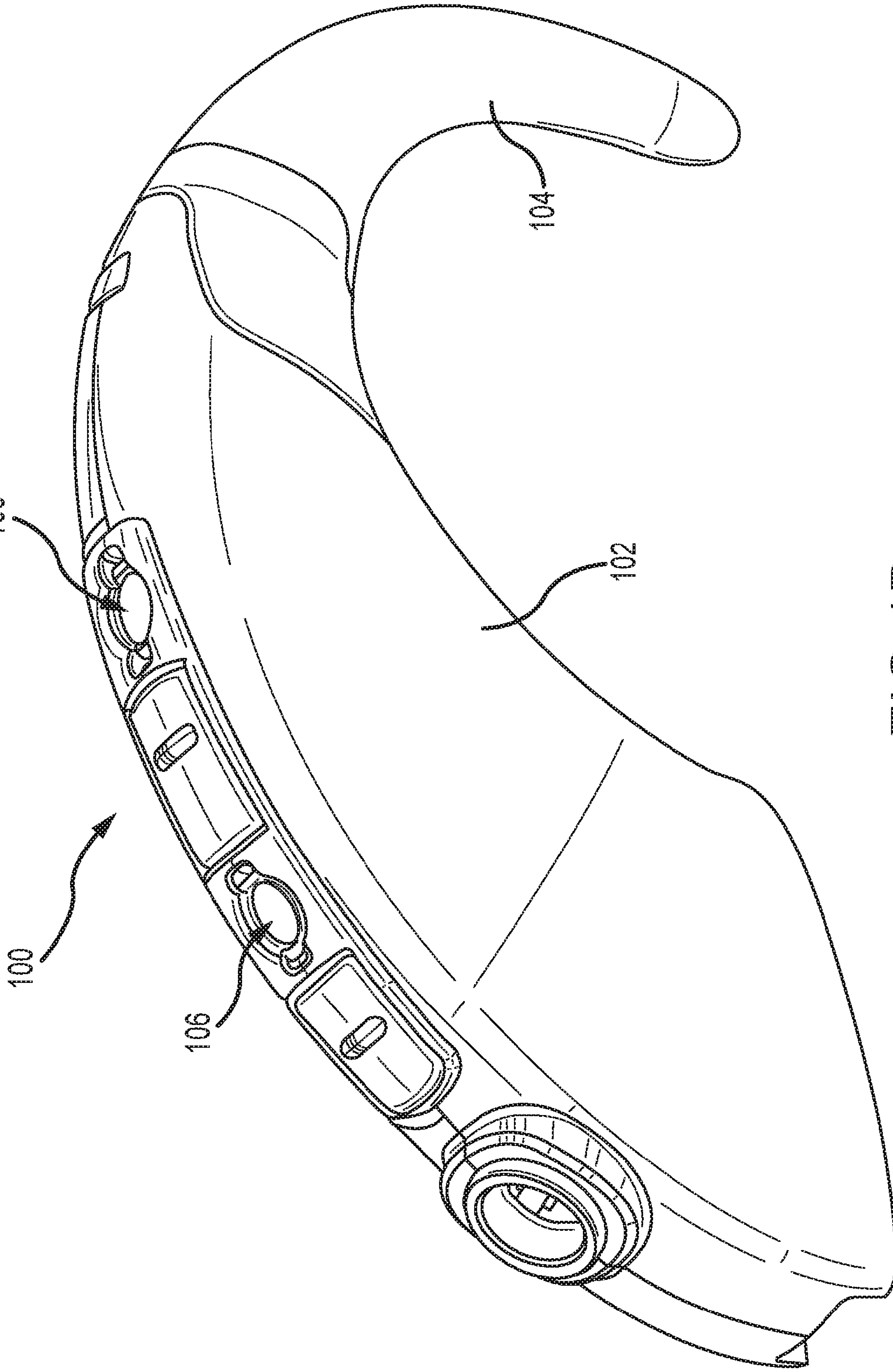


FIG.1B

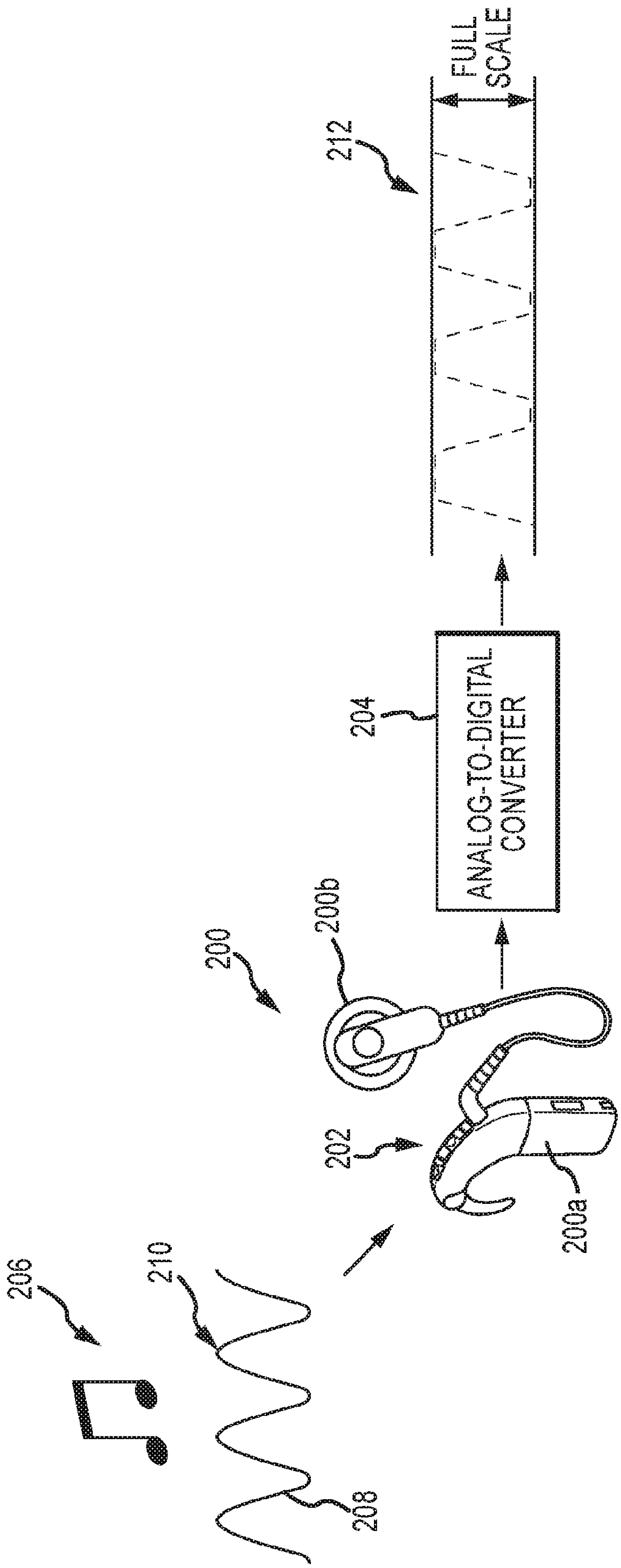

206
210
208
202
200
200b
200a
204
ANALOG-TO-DIGITAL
CONVERTER
212
FULL
SCALE

FIG.2A

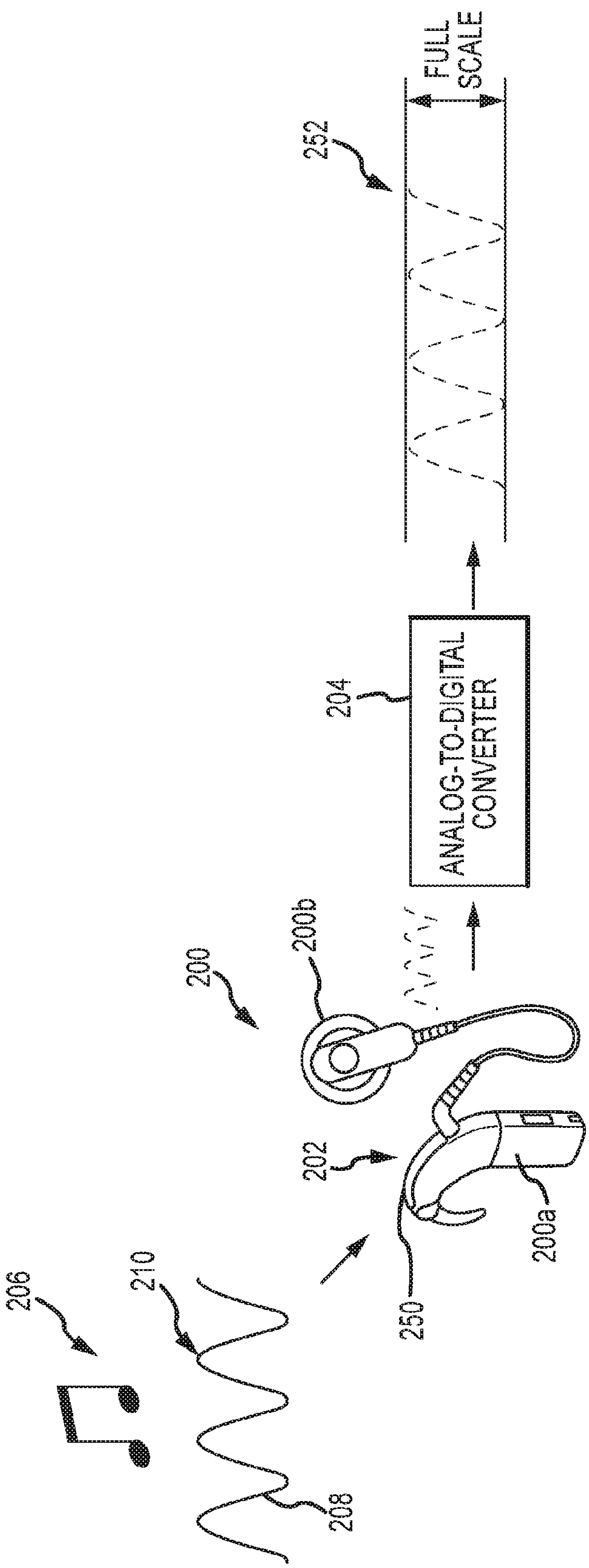

206
210
208
202
250
200a
200
200b
204
ANALOG-TO-DIGITAL CONVERTER
252
FULL SCALE

FIG.2B

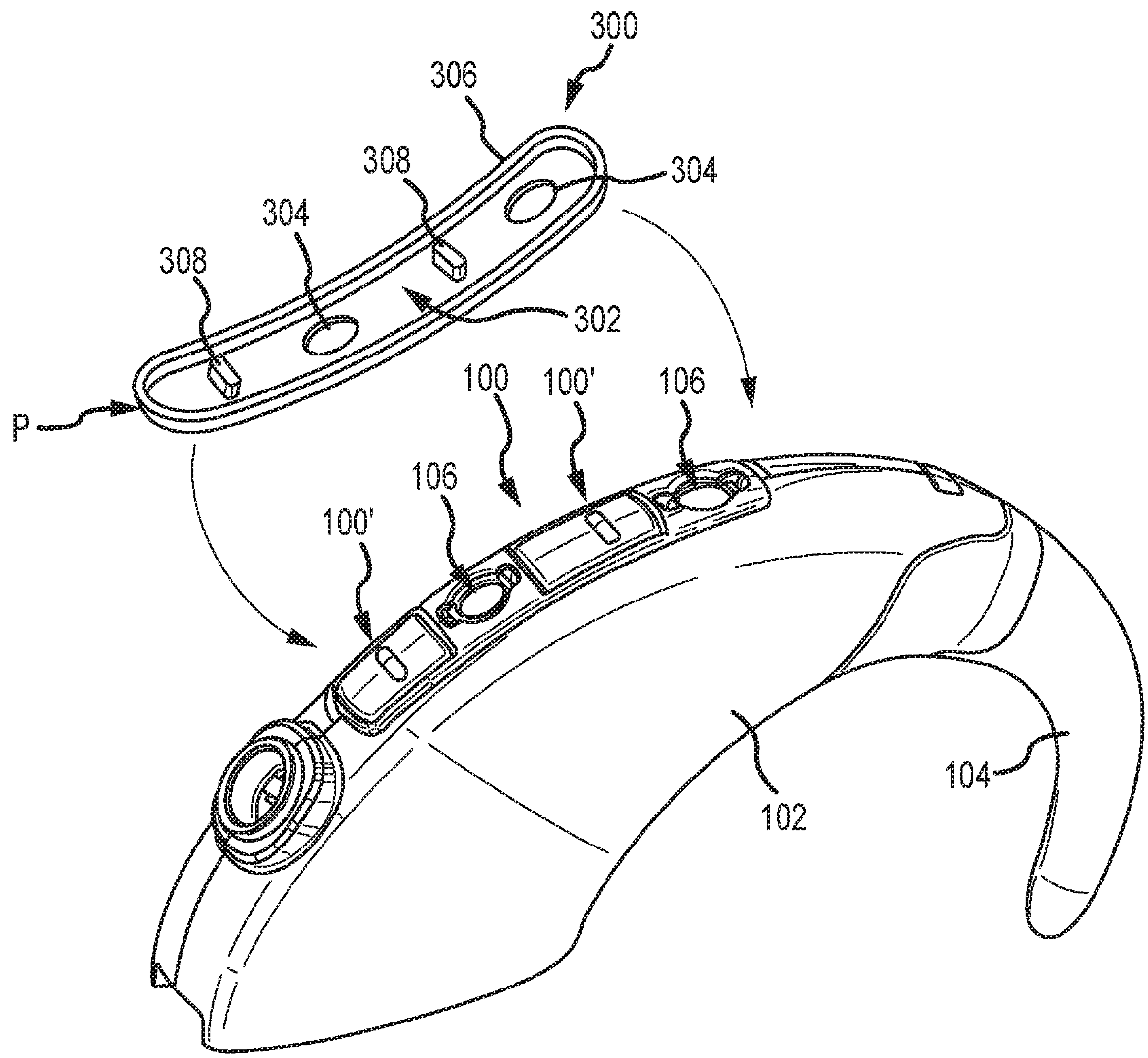


FIG.3A

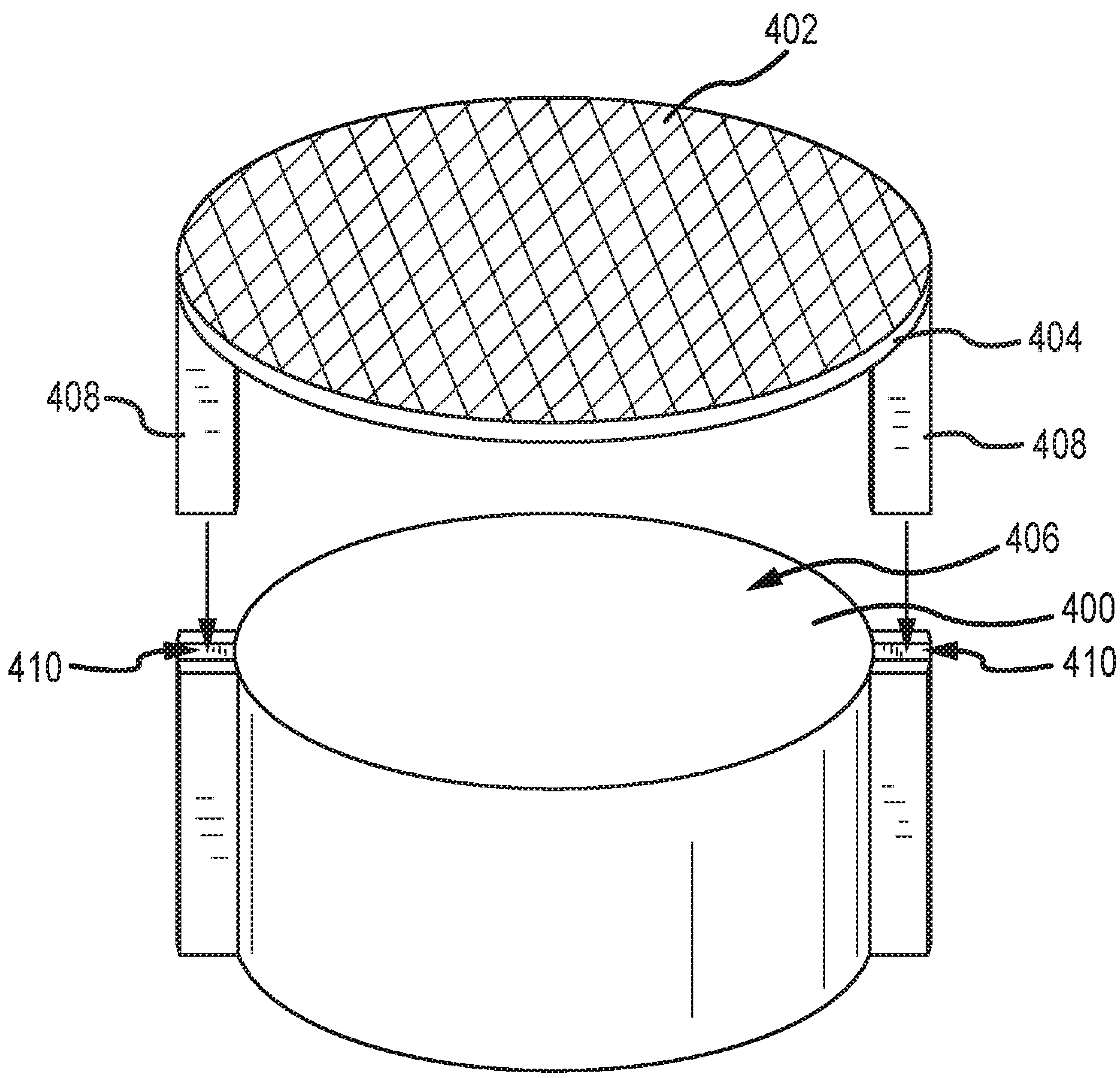


FIG.3B

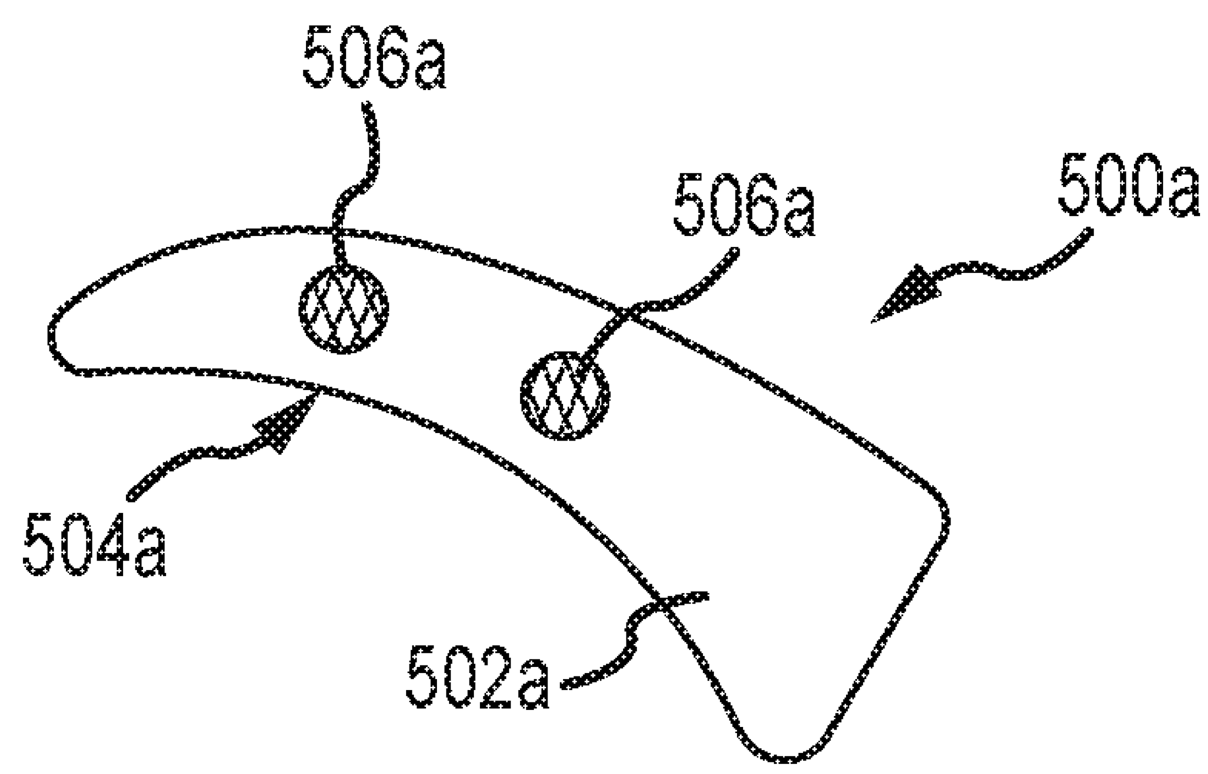


FIG.4A

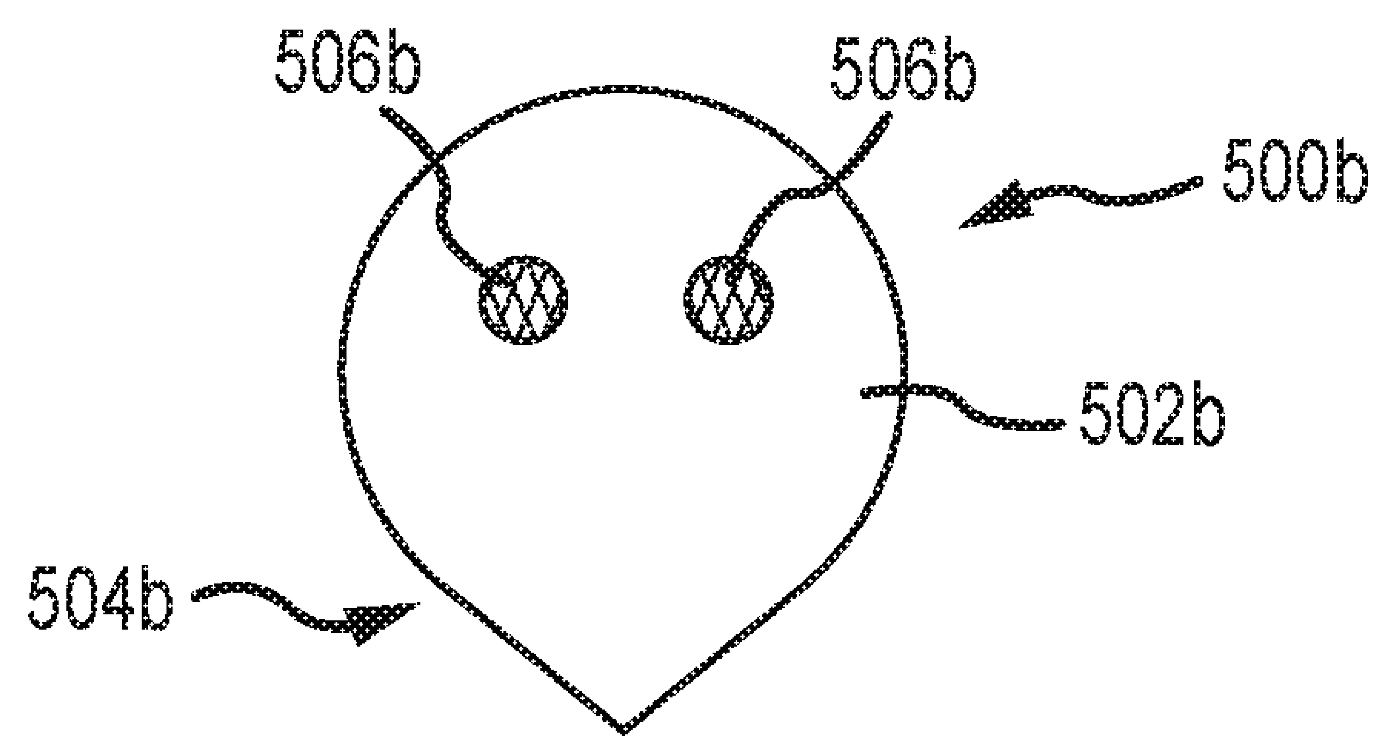


FIG.4B

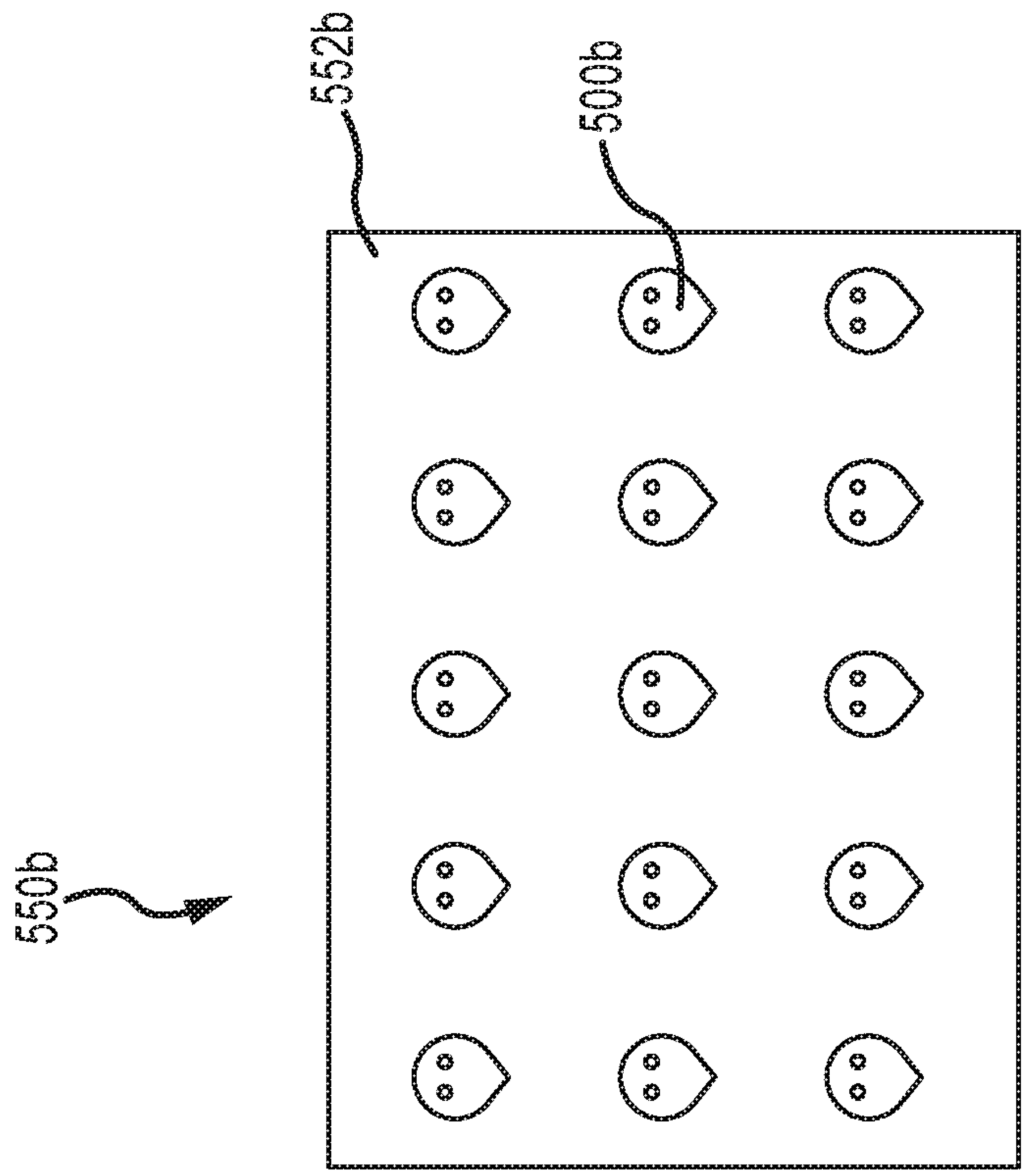


FIG. 5B

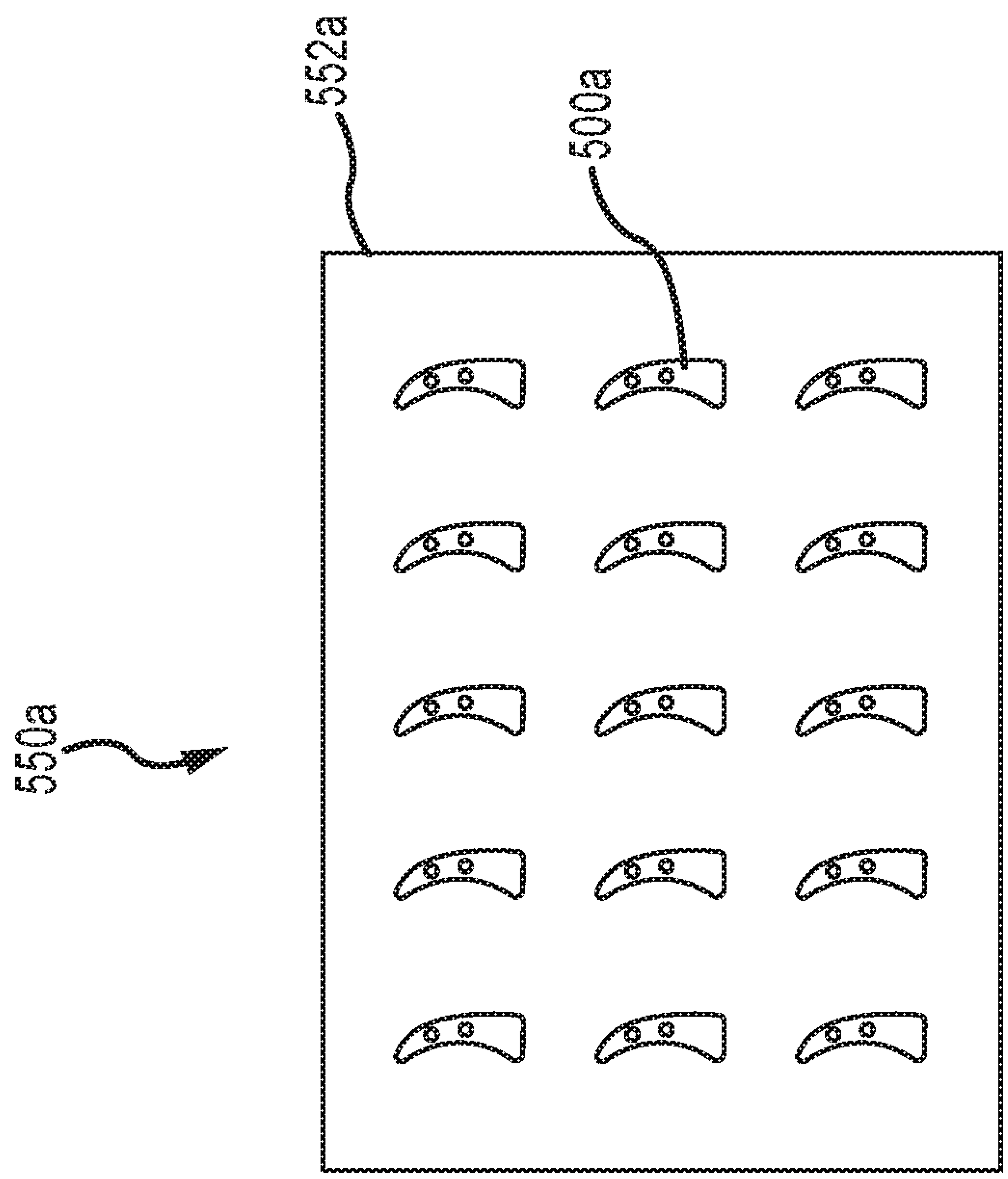


FIG. 5A

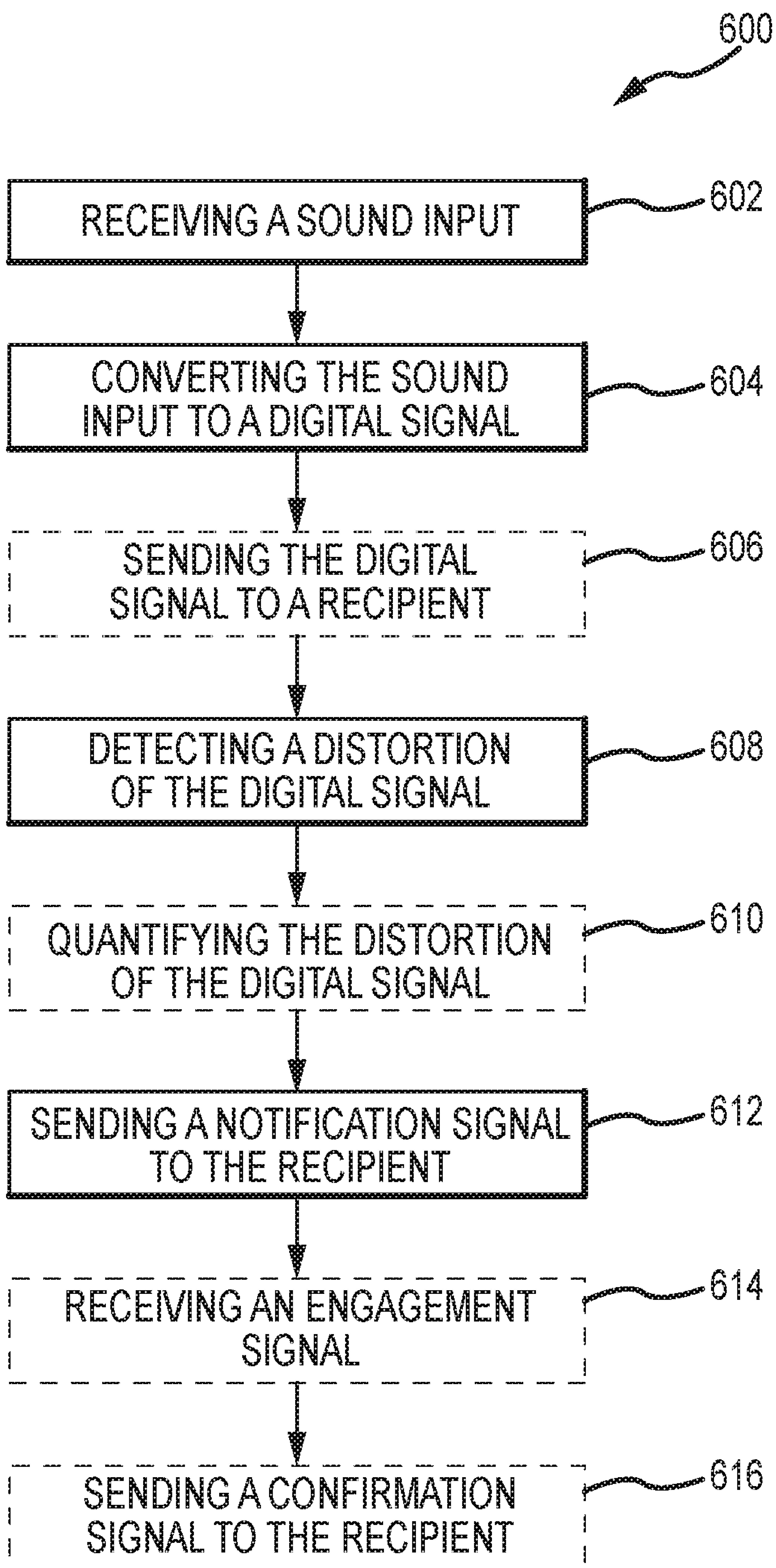

600
RECEIVING A SOUND INPUT
602
CONVERTING THE SOUND INPUT TO A DIGITAL SIGNAL
604
SENDING THE DIGITAL SIGNAL TO A RECIPIENT
606
DETECTING A DISTORTION OF THE DIGITAL SIGNAL
608
QUANTIFYING THE DISTORTION OF THE DIGITAL SIGNAL
610
SENDING A NOTIFICATION SIGNAL TO THE RECIPIENT
612
RECEIVING AN ENGAGEMENT SIGNAL
614
SENDING A CONFIRMATION SIGNAL TO THE RECIPIENT
616

FIG.6A

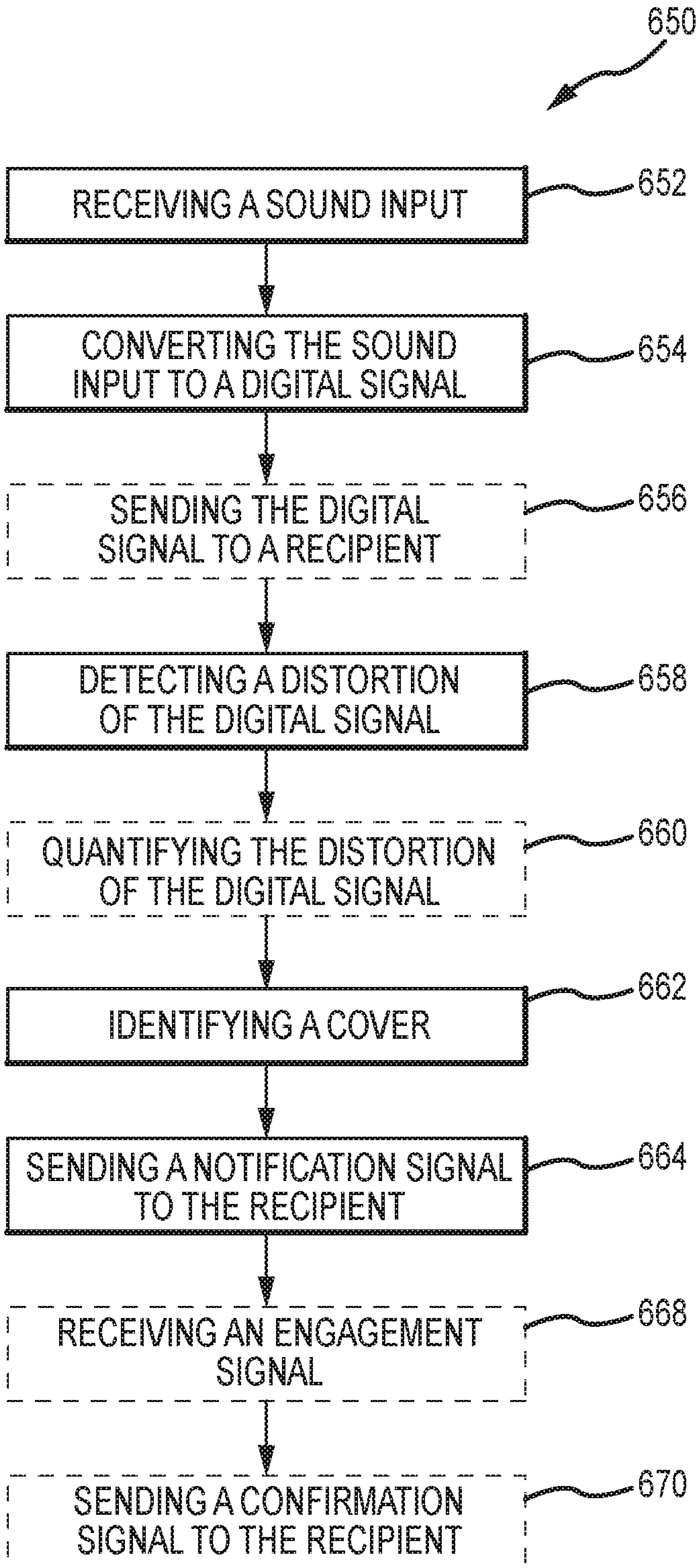

650
RECEIVING A SOUND INPUT
652
CONVERTING THE SOUND INPUT TO A DIGITAL SIGNAL
654
SENDING THE DIGITAL SIGNAL TO A RECIPIENT
656
DETECTING A DISTORTION OF THE DIGITAL SIGNAL
658
QUANTIFYING THE DISTORTION OF THE DIGITAL SIGNAL
660
IDENTIFYING A COVER
662
SENDING A NOTIFICATION SIGNAL TO THE RECIPIENT
664
RECEIVING AN ENGAGEMENT SIGNAL
668
SENDING A CONFIRMATION SIGNAL TO THE RECIPIENT
670

FIG.6B

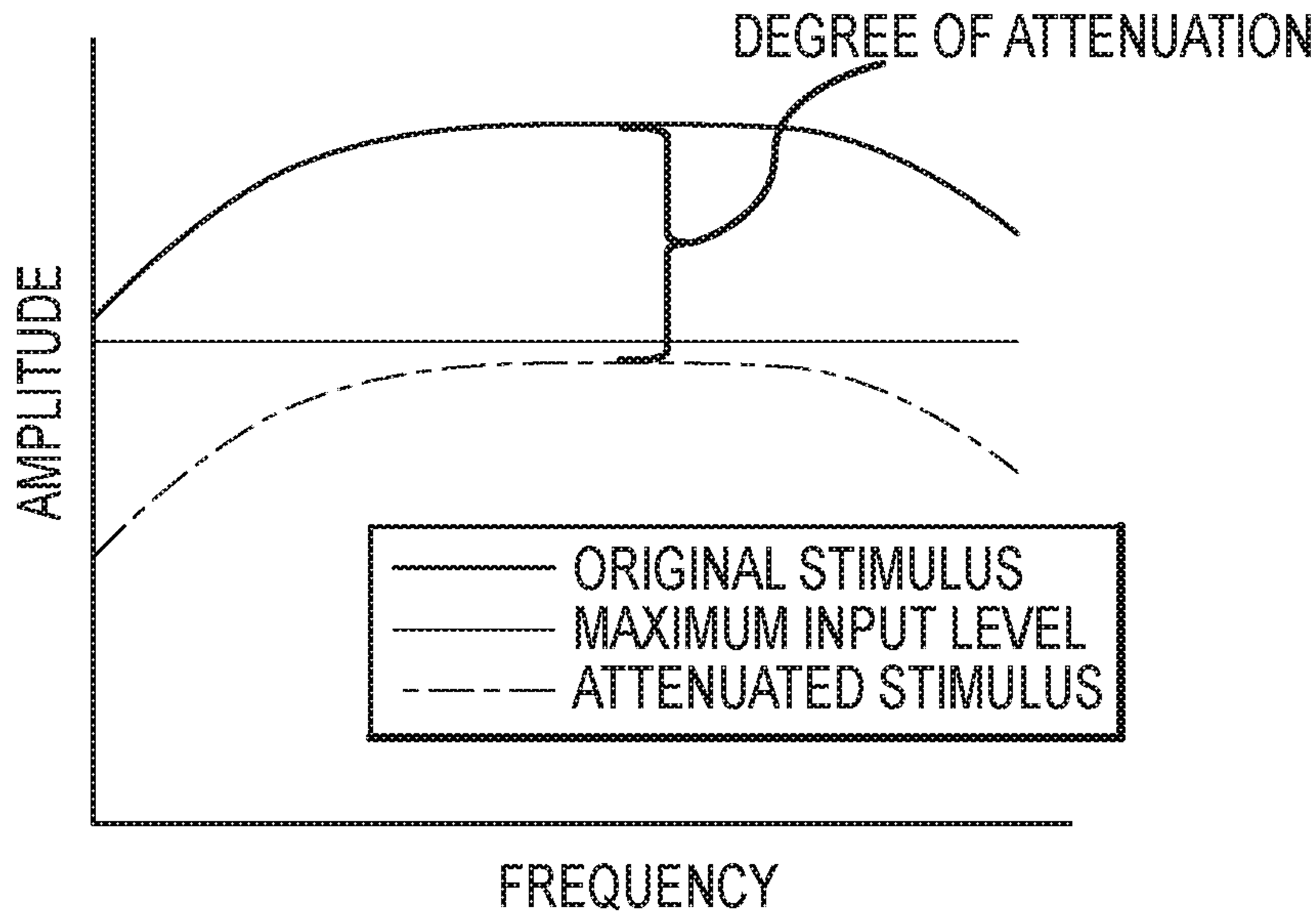

DEGREE OF ATTENUATION
AMPLITUDE
ORIGINAL STIMULUS
MAXIMUM INPUT LEVEL
ATTENUATED STIMULUS
FREQUENCY

FIG.7A

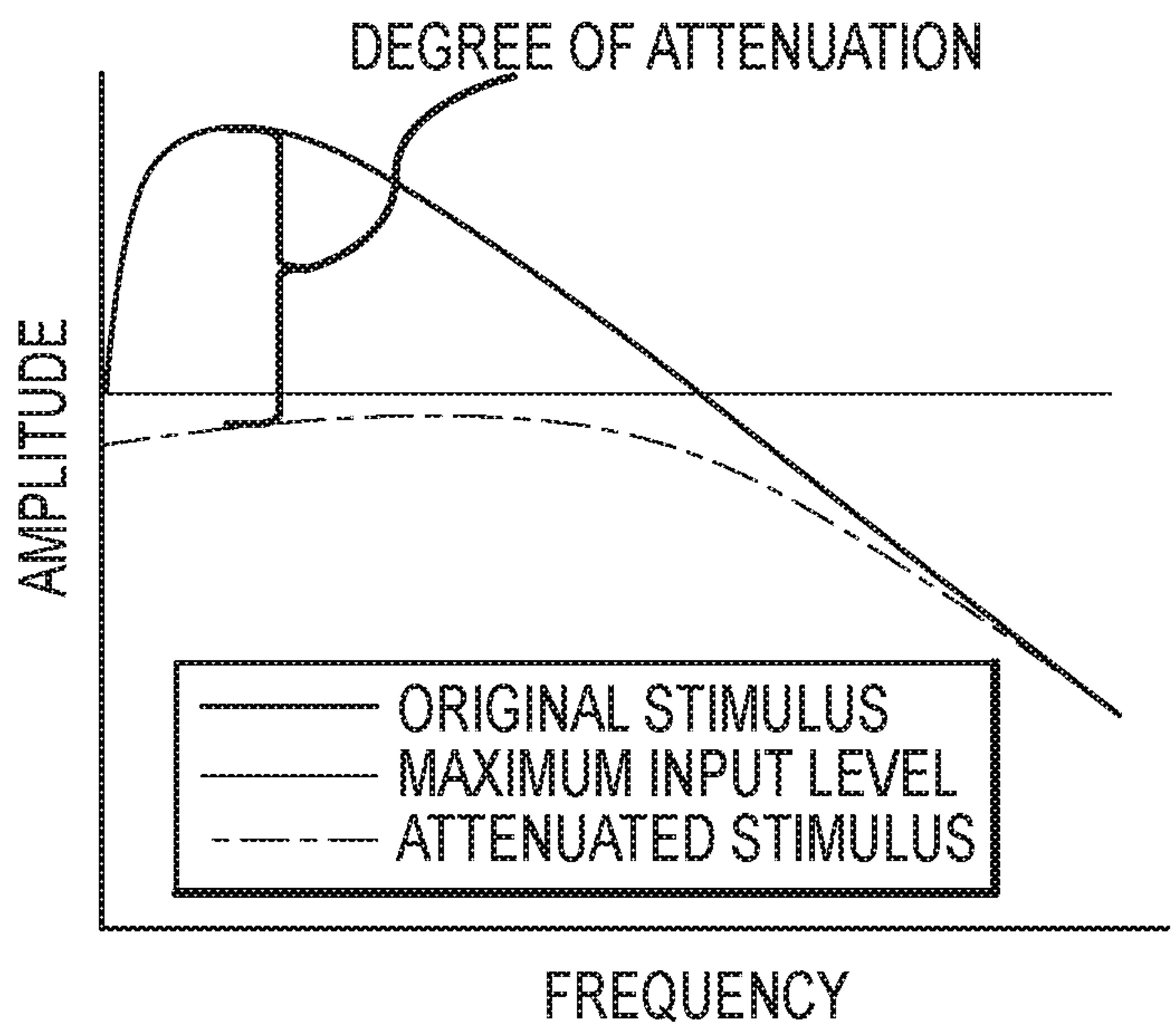
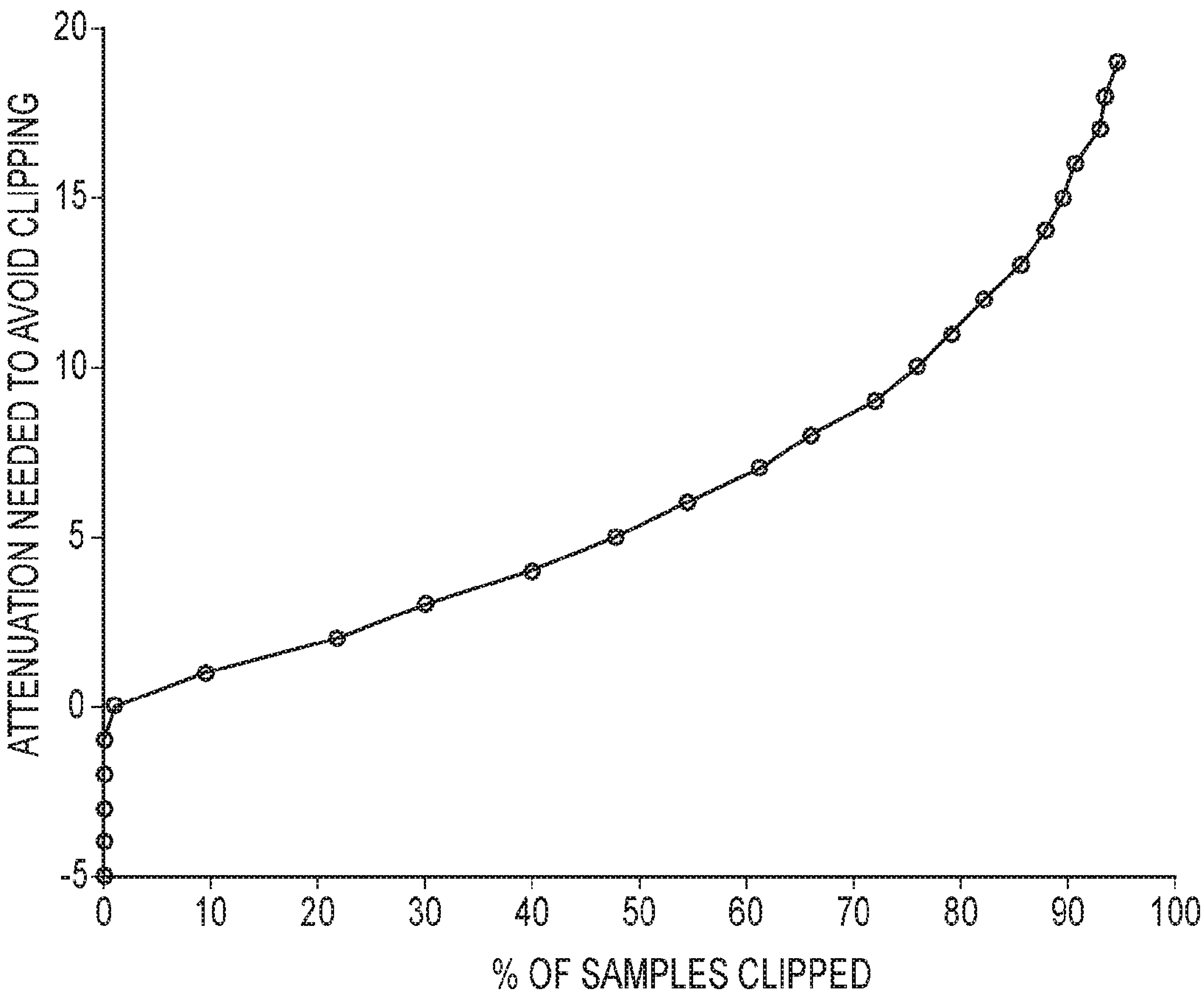

DEGREE OF ATTENUATION
AMPLITUDE
ORIGINAL STIMULUS
MAXIMUM INPUT LEVEL
ATTENUATED STIMULUS
FREQUENCY

FIG.7B



ATTENUATION NEEDED TO AVOID CLIPPING
20
15
10
5
0
-5
0
10
20
30
40
50
60
70
80
90
100
% OF SAMPLES CLIPPED

FIG.8

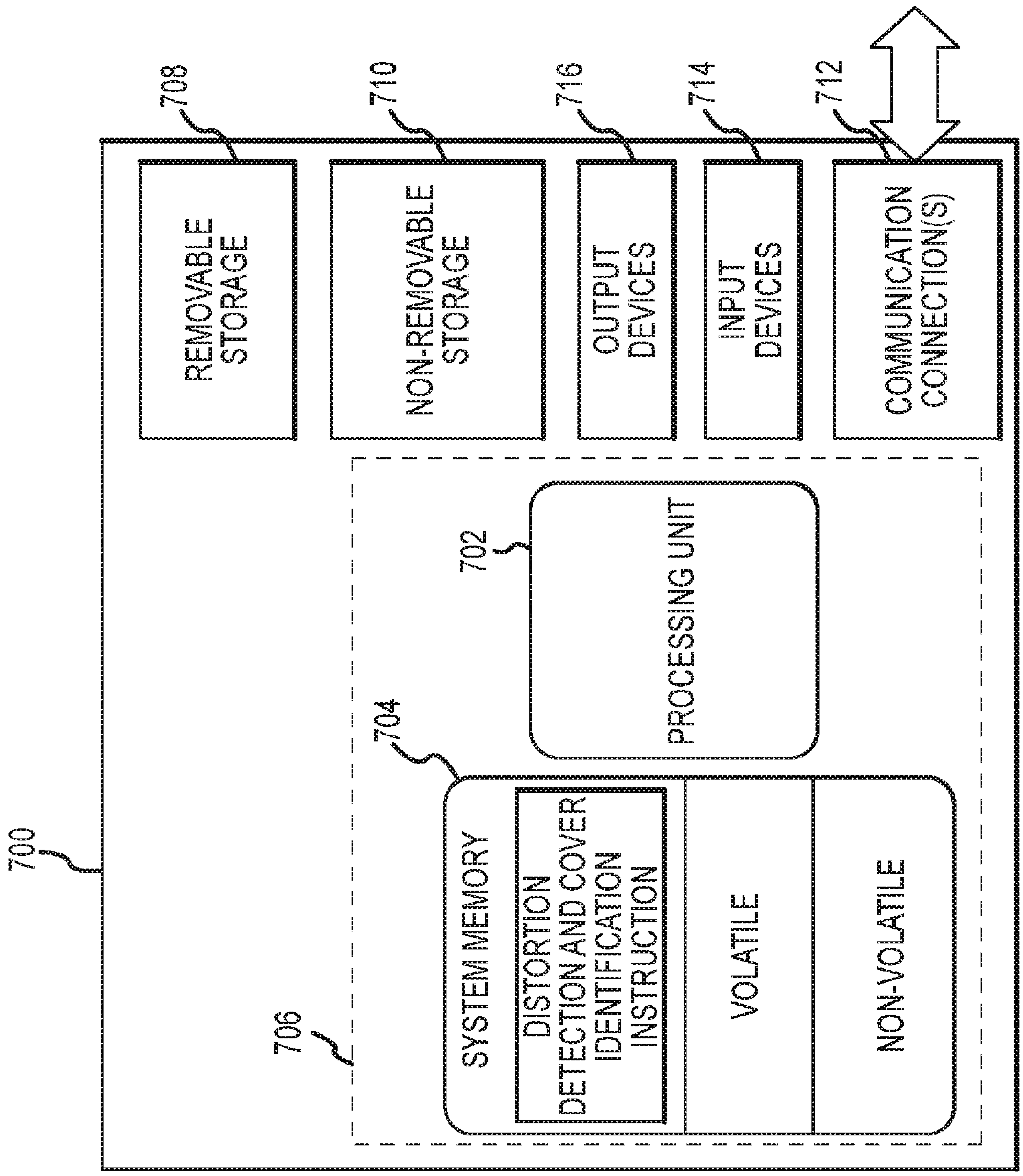

700
706
704
702
708
710
716
714
712
SYSTEM MEMORY
DISTORTION DETECTION AND COVER IDENTIFICATION INSTRUCTION
VOLATILE
NON-VOLATILE
PROCESSING UNIT
REMOVABLE STORAGE
NON-REMOVABLE STORAGE
OUTPUT DEVICES
INPUT DEVICES
COMMUNICATION CONNECTION(S)

FIG.9

SYSTEMS AND METHODS FOR IMPROVING OUTPUT SIGNALS FROM AUDITORY PROSTHESES

BACKGROUND

Hearing loss, which can be due to many different causes, is generally of two types: conductive and sensorineural. Sensorineural hearing loss is due to the absence or destruction of the hair cells in the cochlea that transduce sound signals into nerve impulses. Various hearing prostheses are commercially available to provide individuals suffering from sensorineural hearing loss with the ability to perceive sound. For example, cochlear implants use an electrode array implanted in the cochlea of a recipient (i.e., the inner ear of the recipient) to bypass the mechanisms of the middle and outer ear. More specifically, an electrical stimulus is provided via the electrode array to the auditory nerve, thereby causing a hearing percept.

Conductive hearing loss occurs when the normal mechanical pathways that provide sound to hair cells in the cochlea are impeded, for example, by damage to the ossicular chain or the ear canal. Individuals suffering from conductive hearing loss can retain some form of residual hearing because some or all of the hair cells in the cochlea function normally.

Individuals suffering from conductive or sensorineural hearing loss often receive a conventional hearing aid. Such hearing aids rely on principles of air conduction to transmit acoustic signals to the cochlea. In particular, a hearing aid typically uses an arrangement positioned in the recipient's ear canal or on the outer ear to amplify a sound received by the outer ear of the recipient. This amplified sound reaches the cochlea causing motion of the perilymph and stimulation of the auditory nerve.

In contrast to conventional hearing aids, which rely primarily on the principles of air conduction, certain types of hearing prostheses commonly referred to as bone conduction devices, convert a received sound into vibrations. The vibrations are transferred through the skull to the cochlea causing motion of the perilymph and stimulation of the auditory nerve, which results in the perception of the received sound. Bone conduction devices are suitable to treat a variety of types of hearing loss and can be suitable for individuals who cannot derive sufficient benefit from conventional hearing aids.

SUMMARY

Aspects disclosed herein relate to attenuation covers that are used to reduce the amplitude of input signals at a microphone or other sound-receiving component of an auditory prosthesis. Sound processing or other components in the auditory prosthesis can detect distortion present in the output signal and notify a recipient of the auditory prosthesis that an attenuation cover is recommended or desirable. Use of such a cover can provide a clearer output signal to the recipient, so as to improve the recipient experience. Attenuation covers can be particularly useful in environments where the input sound signals exceed the dynamic range of the auditory prosthesis.

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

The same number represents the same element or same type of element in all drawings.

FIG. **1** is a partial view of an auditory prosthesis worn on a recipient.

FIG. **1**A is a side perspective view of an external portion of an auditory prosthesis.

FIG. **1**B is a side perspective view of a behind-the-ear portion of an auditory prosthesis.

FIG. **2**A is a schematic depiction of distorted output of an auditory prosthesis.

FIG. **2**B is a schematic depiction of an output of an auditory prosthesis utilized in conjunction with an attenuation cover.

FIG. **3**A is a side perspective view of the behind-the-ear portion of FIG. **1**B and an example of an attenuation cover.

FIG. **3**B depicts a side perspective view of a microphone and another example of an attenuation cover.

FIGS. **4**A and **4**B depict other examples of attenuation covers.

FIGS. **5**A and **5**B depict examples of storage systems for the attenuation covers of FIGS. **4**A and **4**B, respectively.

FIG. **6**A depicts a method of reducing output signal distortion in an auditory prosthesis.

FIG. **6**B depicts another method of reducing output signal distortion in an auditory prosthesis.

FIG. **7**A is a schematic graph depicting an unmodified acoustic stimulus and a modified acoustic stimulus resulting from use of a flat attenuation cover with an auditory prosthesis.

FIG. **7**B is a schematic graph depicting an unmodified acoustic stimulus and a modified acoustic stimulus resulting from use of a high-pass attenuation cover with an auditory prosthesis.

FIG. **8** is a graphical representation of an attenuation level determination algorithm.

FIG. **9** depicts one example of a suitable operating environment in which one or more of the present examples can be implemented.

DETAILED DESCRIPTION

The technologies disclosed herein can be used in conjunction with various types of auditory prostheses, including active transcutaneous bone conduction devices, passive transcutaneous devices, middle ear devices, cochlear implants, totally implantable cochlear implants, and acoustic hearing aids (that are disposed within the ear or supported from the ear). In general, any type of auditory prosthesis that utilizes a microphone, transducer, or other sound-receiving component can benefit from the technologies described herein. Additionally, the technologies can be incorporated into other devices that receive sound and send a corresponding stimulus to a recipient. The corresponding stimulus can be in the form of electrical signals, mechanical vibrations, or acoustic sounds. For clarity, however, the technologies disclosed herein will be generally described in the context of microphones used in behind-the-ear auditory prostheses, as used in conjunction with a cochlear implant.

Referring to FIG. **1**, cochlear implant system **10** includes an implantable component **44** typically having an internal receiver/transceiver unit **32**, a stimulator unit **20**, and an elongate lead **18**. The internal receiver/transceiver unit **32** permits the cochlear implant system **10** to receive and/or transmit signals to an external device **100** and includes an internal coil **36**, and preferably, a magnet (not shown) fixed relative to the internal coil **36**. These signals generally correspond to external sound **13**. Internal receiver unit **32** and stimulator unit **20** are hermetically sealed within a biocompatible housing, sometimes collectively referred to as a stimulator/receiver unit. The magnets facilitate the operational alignment of the external and internal coils, enabling internal coil **36** to receive power and stimulation data from external coil **30**. The external coil **30** is contained within an external portion attached to a head of a recipient. Elongate lead **18** has a proximal end connected to stimulator unit **20**, and a distal end implanted in cochlea **40**. Elongate lead **18** extends from stimulator unit **20** to cochlea **40** through mastoid bone **19**.

In certain examples, external coil **30** transmits electrical signals (e.g., power and stimulation data) to internal coil **36** via a radio frequency (RF) link, as noted above. Internal coil **36** is typically a wire antenna coil comprised of multiple turns of electrically insulated single-strand or multi-strand platinum or gold wire. The electrical insulation of internal coil **36** is provided by a flexible silicone molding. Various types of energy transfer, such as infrared (IR), electromagnetic, capacitive and inductive transfer, can be used to transfer the power and/or data from external device to cochlear implant.

There are a variety of types of intra-cochlear stimulating assemblies including short, straight and peri-modiolar. Stimulating assembly **46** is configured to adopt a curved configuration during and or after implantation into the recipient's cochlea **40**. To achieve this, in certain arrangements, stimulating assembly **46** is pre-curved to the same general curvature of a cochlea **40**. Such examples of stimulating assembly **46**, are typically held straight by, for example, a stiffening stylet (not shown) or sheath which is removed during implantation, or alternatively varying material combinations or the use of shape memory materials, so that the stimulating assembly can adopt its curved configuration when in the cochlea **40**. Other methods of implantation, as well as other stimulating assemblies which adopt a curved configuration, can be used.

Stimulating assembly can be a peri-modiolar, a straight, or a mid-scala assembly. Alternatively, the stimulating assembly can be a short electrode implanted into at least in basal region. The stimulating assembly can extend towards apical end of cochlea, referred to as cochlea apex. In certain circumstances, the stimulating assembly can be inserted into cochlea via a cochleostomy. In other circumstances, a cochleostomy can be formed through round window, oval window, the promontory, or through an apical turn of cochlea.

Speech processing components, such as microphones, speech processing hardware and software, and other elements, can be disposed within a housing separate from the implantable portion of the auditory prosthesis. In certain examples, such components can be contained in an external portion that also includes the external coil described above. In another example, the sound processing components can be contained within a so-called behind-the-ear (BTE) device, such as BTE **100** depicted in FIG. **1**. In the latter case, signals from the sound processing components are sent to an external portion containing the external coil. Both an external portion containing sound processing components and a BTE containing sound processing components are described below in FIGS. **1**A and **1**B, respectively. The technologies described further herein can be incorporated into either type of devices, as required or desired for a particular application.

FIG. **1**A is a perspective view of type of an external portion **50** of an auditory prosthesis. The external portion **50** includes a body **52** and the external coil **30** connected thereto. The function of the external coil **30** is described above with regard to FIG. **1**. The body **52** can include a permanent magnet **56** as described above, which helps secure the external portion **50** to the recipient's skull. The external portion **50** can include an indicator **58** such as a light emitting diode (LED). A battery door **60** covers a receptacle that includes a battery that provides internal power to the various components of the external portion **50** and the implantable portion. A microphone **62** receives sound that is processed by sound-processing components within the external portion **50**.

FIG. **1**B depicts another type of an external portion **100** (more specifically, a BTE) of an auditory prosthesis. The BTE **100** includes a housing **102** and an ear hook **104** extending therefrom to help secure the BTE **100** to the ear of a recipient. The ear hook **104** helps secure the BTE **100** to a recipient by wrapping around the upper portion of the ear. The housing **102** of the BTE **100** defines one or more openings **106** that allow sound to travel into the housing **102**, to a microphone or other sound-receiving element disposed therein. These openings **106** form a penetration in the housing **102** that can allow water, dirt, or other debris to enter the housing **102**. Such ingress can damage the microphone and/or other elements within the housing **102**. In the depicted embodiment, the openings **106** are depicted as round in shape, but openings having other shapes are contemplated. The technologies described herein are described in the context of microphones utilized in the BTE **100** that is worn on the ear of a recipient, even though, as noted above, the technologies can be utilized with external portions that also contain the external coil.

FIG. **2**A is a schematic depiction of distorted output of an auditory prosthesis **200**, which is depicted generally as a BTE device **200***a* connected to an external coil **200***b*. As described above, any type of auditory prosthesis, as well as traditional hearing aids, can be utilized. The auditory prosthesis **200** includes, at a minimum, a microphone in communication with at least one microphone opening **202** in the BTE device **200***a* and speech processing components including at least an analog-to-digital converter **204** (depicted outside the auditory prosthesis **200** for illustrative purposes). In general, an auditory prosthesis **200** performs generally better when delivering stimuli in quieter environments. The sound quality of live music **206**, however, is often compromised for a number of reasons. Live music **206** is generally a more intense input signal **208** than recorded music or speech and often has higher crest factors than speech, meaning that the peaks **210** of the input signal **208** are much higher in comparison to the average sound input levels. As such, the peaks **210** of live music input signals **208** can be well over a sound pressure level (SPL) of 100 dB. The live music input signals **208** pass into the microphone opening **202** in the BTE device **200**, where they are received by the microphone and processed. The digital architectures of the sound processors of the auditory prosthesis **200** (e.g., the analog-to-digital converter **204**) result in a fixed dynamic range. In an example, 16 bits can represent a dynamic range of up to about 90 dB. Because the peaks **210** of the live music input signals **208** are frequently above the top of this dynamic range, the live music signal **208** is often peak-clipped at the analog-to-digital converter **204**, causing distortion. The distortion is present at the output of the analog-to-digital converter **204** as a clipped output signal **212**. Once this distortion is present, further software and sound coding manipulations cannot restore the "clean" signal, leading to reduced sound quality for recipients. Thus, known sound processing technologies that reduce sensitivity, volume, or other sound characteristics cannot adequately modify the input signal **208** so as to obtain a desired output signal.

FIG. **2**B is a schematic depiction of an output of an auditory prosthesis **200** utilized in conjunction with an attenuation cover **250**. Many of the components depicted in FIG. **2**B are described with regard to FIG. **2**A and are therefore not necessarily described further. The attenuation cover **250** reduces the front-end peak-clipping that routinely occurs in live music environments and is depicted and described above in FIG. **2**A. When listening to live music, the recipient can place the attenuation cover **250** over the microphone openings **202** of the auditory prosthesis **200** to attenuate the level of the input signal **208**. Different types and configurations of attenuation covers are contemplated and described in further detail below. In the depicted embodiment, the attenuation cover **250** is an external, removable component that is designed to be used as required or desired. In one example, the attenuation cover **250** has a flat frequency response so that the spectrum of the music **206** is left intact. When the attenuation cover **250** is attached and in place, the attenuated level of the input signal **208** will be within the dynamic range of the analog-to-digital converter **204**. Therefore, the incoming music input signal **208** will be preserved upon entering the sound processing components, leading to improved fidelity in the music output signal **252**. This less distorted signal **252** (or in certain examples, entirely undistorted signal) will enhance perceived music quality for the recipient. The signal **252** can be further processed, if required or desired, for a particular application.

FIG. **3**A is a side perspective view of the BTE portion **100** of FIG. **1**B and an example of an attenuation cover **300**. Various components of the BTE portion **100** are described above with regard to FIG. **1**B and are not necessarily described further. In addition to the components described above, one or more openings **100'** are formed within a portion of the housing **102**, proximate the microphone openings **106**. The purposes of these openings **100'** are described below. The attenuation cover **300** has a generally rigid body **302** that is sized to cover one or more of the microphone openings **106** that are defined by the housing **102**. The rigid body **302** can have known attenuation properties as described in more detail below. To prevent attenuated sound from reaching the microphone openings **106** (and accordingly, the microphones), it is desirable that the rigid body **302** or portions thereof form a sealed volume at the microphone openings **106**. Such a sealed volume can be formed over each microphone opening **106**, with a plurality of sealing elements **304**. Alternatively, the sealed volume can be formed over both microphone openings **106**, together, with a single sealing element **306**. In the depicted embodiment, sealing element **306** is disposed about a perimeter P of the rigid body **302**, although other locations are contemplated. In certain examples, sealing elements **304**, **306** can both be included to ensure an adequate seal. The sealing elements **304**, **306** form an uninterrupted contact surface with the housing **102** and can be formed of a resilient gasket or other element that is generally secured to the rigid body **302**. A removable adhesive can be disposed on a face of the sealing element **304**, **306** to ensure further contact with the housing **102**.

The sealing elements **304**, **306** are configured to contact and uncontact from the housing without damaging either the attenuation cover **300**, the rigid body **302**, the sealing elements **304**, **306** themselves, the housing **102**, and so on. Easy application and removal of the attenuation cover **300** is desirable because the covers described herein are configured to be applied and removed as circumstances dictate. Thus, it is desirable that this occurs without damaging the housing or leaving adhesive residue on any portion of the device. It is also advantageous that the covers described herein be applied and removed without requiring the recipient to remove their auditory prosthesis. The attenuation cover **300** can also include one or more keys **308** projecting therefrom that are configured to mate with the openings **100'**. This mating engagement is described in further detail below and can be used to secure the cover **300** to the device **100**, or to trigger a signal that can be used by the BTE **100** to identify the type of cover **300** being utilized, performance characteristics (e.g., attenuation characteristics), and so on. In other examples, a signal can be triggered by RFID elements, proximity sensors, electrical contacts, or other components, disposed in either or both of the attenuation cover **300** or the device **100**.

FIG. **3**B depicts a side perspective view of a microphone **400** and another example of an attenuation cover **402**. Here, the microphone **400** can be disposed within the body of a BTE or an external portion of an auditory prosthesis. The attenuation cover **402** can include a sealing element **404** disposed on a surface thereof and configured to engage with the body (e.g., an upper surface **406**) of the microphone **400** so as to form a sealed volume thereon, as described above. The attenuation cover **402** can also include one or more keys **408** configured to engage one or more keyholes or openings **410** disposed proximate the microphone **400**. This engagement can secure the cover **402** to the device and/or microphone **400**, trigger a signal to be used by the device, and for other purposes as described herein. Affirmative engagement of a portion of the attenuation cover **402** with either or both of the microphone **400** and the device body can help ensure a sealed volume is formed proximate the inlet to the microphone **400**. In certain examples, engagement elements that provide tactile feedback (in the form of, e.g., detents or other elements) can be desirable to ensure proper engagement.

FIGS. **4**A and **4**B depict other examples of attenuation covers **500***a*, **500***b*. The attenuation cover **500***a* has a form factor configured to match that of a BTE device. In this example, a body **502***a* of the attenuation cover **500***a* can be manufactured of a flexible or semi-flexible material that has disposed on an underside **504***a* thereof a removable contact adhesive. This allows the attenuation cover **500***a* to be applied and removed as required or desired. The body **502***a* can include one or more substantially rigid portions **506***a* disposed so as to align with a corresponding number of microphone openings on the BTE. In an alternative example, one rigid portion **506***a* can be used to cover more than one microphone opening. Thus, the rigid portions **506***a*, in conjunction with the contact adhesive on the underside **504***a* of the body **502***a* form the sealed volume once attached to the BTE. To help ensure the desired attenuation, the rigid portions **506***a* can be oversized, relative to the microphone openings, such that when secured to the BTE device, only the rigid portions **506***a* cover the openings. Additional sealing elements in the form of thin gaskets or additional adhesive can be disposed proximate the rigid portions **506***a* to ensure a sealed volume is formed.

The attenuation cover **500***b* has a form factor configured to match that of a traditional hearing aid device that is inserted into the ear canal. Similar to the example described in FIG. **4**A, a body **502***b* of the attenuation cover **500***b* can be manufactured of a flexible or semi-flexible material that has disposed on an underside **504***b* thereof a removable contact adhesive. As above, the body **502***b* can include one or more substantially rigid portions **506***b* disposed so as to cover one or more microphone openings on the device. The rigid portions **506***b* can be oversized, relative to the microphone openings on the device such that when secured to the hearing aid device, only the rigid portions **506***b* cover the openings. Additional sealing elements in the form of thin gaskets or additional adhesive can be utilized to ensure a sealed volume is formed.

FIGS. **5**A and **5**B depict examples of storage systems **550***a*, **550***b* for the attenuation covers **500***a*, **500***b* of FIGS. **4**A and **4**B, respectively. The storage systems **550***a*, **550***b* include a releasable contact sheet **552***a*, **552***b* having a plurality of attenuation covers **500***a*, **500***b* disposed thereon. When desired, a recipient can remove an attenuation cover **500***a*, **500***b* and secure it to their device. After use, the attenuation covers **500***a*, **500***b* can be removed and discarded. In examples, a single sheet **552***a*, **552***b* can include a plurality of attenuation cases **500***a*, **500***b*, where two or more of which can display different attenuation properties. Covers **500***a*, **500***b* can be grouped in distinct areas on the sheets **552***a*, **552***b* or colored, marked, or otherwise identified.

FIG. **6**A depicts a method **600** of reducing signal output, distortion in an auditory prosthesis. The method **600** may be implemented using hardware, software, or a combination of hardware and software. The method **600** begins by receiving a sound input, generally at an auditory prosthesis, at operation **602**. Flow continues to operation **604**, where the received sound input is converted into a digital signal, for example, by passing the input through an analog-to-digital converter, as is common for auditory prostheses such as cochlear implants, bone conduction devices, etc. When the method is performed by a traditional hearing aid, operation **604** can be can additionally or alternatively include amplifying the received sound input. Flow continues to optional operation **606** where the digital signal is sent to a recipient. The technologies described herein further analyze and process the sound input so as to improve the experience of the prosthesis recipient. For example, at operation **608**, the digital signal is analyzed to detect distortion. Detection of distortion is discussed in more detail below. At optional operation **610**, a level of the detected distortion of the digital signal is quantified. Quantification of the digital signal is described in further detail below. In operation **612**, a notification is sent.

The notification can be one or more of several different signals. For example, a notification signal can be a unique tone, pulse, or other signal distinct from the digital signals (and therefore the sounds being perceived by the recipient). In another example, a notification can be a termination of the digital signal sent to the recipient in operation **606**. For example, the digital signal representing the stimulus to the recipient can cease completely or intermittently, so as to be noticed by the recipient. In another example, the unique tone, pulse, or signal can be followed by a termination of the digital stimulus signal. Additionally or alternatively, a notification signal can be sent to a device remote from the auditory prosthesis, such as a smartphone, which can display an alert to the recipient. Regardless of the type of notification used, the notification acts as a signal to the recipient to apply an attenuation cover to their device to mitigate the level of distortion caused by the input signal being received at the auditory prosthesis. Different notification signals can correspond to different attenuation covers. For example, a steady unique tone can signal the recipient to apply a cover that corresponds, for example, to 10 dB of attenuation. A different, perhaps intermittent, tone can signal the recipient to apply a cover that corresponds to 20 dB of attenuation.

Further operations in the method **600** can also improve recipient experience. For example, at optional operation **614** an engagement signal can be received if the recipient applies a cover having a key (such as described above). Subsequent thereto, at optional operation **616** a confirmation signal can be sent to the recipient e.g., so the recipient is ensured that the attenuation cover has been properly applied. Upon receipt of the engagement signal, the auditory prosthesis can continue to analyze the signal for distortion (e.g., repeating the method **600** beginning at operation **602**). Continued distortion can cause the auditory prosthesis to send a signal for the recipient to apply an attenuation cover having greater attenuation than the first applied cover, for example.

FIG. **6**B depicts another method of reducing signal output distortion in an auditory prosthesis. The method **650** begins by receiving a sound input, operation **652**, which is then converted into a digital signal, operation **654**. In optional operation **656**, the digital signal is sent to a recipient, operation **656**. In operation **658**, distortion of the digital signal is detected and in operation **660**, the level of distortion of the digital signal can be quantified. In an example, optional operation **660** includes determining if the distortion is in excess of a predetermined threshold that is stored on the auditory prosthesis. Based at least in part on the quantified level of distortion, an attenuation cover displaying a known attenuation characteristic can be identified, operation **662**. This cover can be selected from a plurality of covers each having known attenuation characteristics. The sound processing components of the auditory prosthesis can include a look-up table or other resource that correlates sound attenuation characteristics with particular covers.

The identification operation can include selecting an attenuation cover based on a minimum attenuation required to reduce the distortion to less than the predetermined threshold. In one example, the predetermined threshold is based on a sound pressure level (SPL). If the threshold SPL is 90 dB and the received input sound is 97 dB, the method **650** determines that a reduction of 7 dB is required to reduce the SPL to the threshold level. The component performing the method **650** can be programmed to select from, e.g., three covers with three different attenuation characteristics (e.g., Cover A, 5 dB attenuation; Cover B, 10 dB attenuation; and Cover 3, 20 dB attenuation). Thus, the system would identify Cover B as meeting the attenuation requirements. In another example, the predetermined threshold can be based on a number of distorted digital signal samples, which is described in more detail below.

Upon identifying the appropriate attenuation cover, operation **664** sends a notification can be sent to the recipient. Exemplary notifications are described above. The recipient can then apply the identified cover to her auditory prosthesis. To ensure the correct cover is applied by the recipient, attenuation covers can include markings, be color-coded, disposed on particular areas of the storage systems described above, etc. As described above, optional operation **668** receives an engagement signal and optional operation **670** sends a confirmation signal can be sent to the recipient. The auditory prosthesis can continually monitor input signals so as to detect distortion. Continued distortion can cause the auditory prosthesis to send a signal for the recipient to apply an attenuation cover having greater or lesser attenuation than the cover first applied, and/or notify the recipient when the attenuation cover can be removed without causing an adverse effect on performance.

In addition to identifying and recommending attenuation covers based on detected and/or quantified distortion, the technologies described herein can also identify attenuation covers utilizing scene classification technology, as described generally in U.S. Pat. Nos. 8,605,923 and 8,824,710, the disclosures of which are hereby incorporated by reference in their entireties. In scene classification technology, the sound processor of an auditory prosthesis or hearing aid can classify the auditory environment which the recipient is located, based on input signals received therefrom. An alert or notification can then be issued to prompt the recipient to apply the attenuator that is most appropriate for the particular environment. Attenuation covers can be optimized for use in various scenes. In non-limiting examples, attenuation covers are described below for four different auditory environments: music, speech in noise, wind, and noise. Other auditory environments are contemplated.

When the auditory scene is classified as music or speech in noise, and the input signal level exceeds the input dynamic range, the auditory prosthesis can prompt or notify the recipient to apply an attenuation cover with flat attenuation characteristics that reduces the amplitude of the input signal across frequencies. FIG. **7**A is a schematic graph depicting an unmodified acoustic stimulus (in the form of an input signal) and a modified or attenuated acoustic stimulus (input signal) resulting from use of such a flat attenuation cover. Here, the original input signal is above the input dynamic range of the auditory prosthesis. After placement or application of an attenuator cover, the amplitude of the input signal is reduced by an equal amount across frequencies. Flat attenuation can be appropriate for speech in noise because of the known difficulties encountered in separating speech from background noise based on frequency alone. The attenuation of the input signals will help reduce or entirely prevent front-end distortion prior to any further signal processing applied (e.g., compression, microphone directionality).

Another type of scene includes those where wind or other types of steady background noise are present. These environments are often characterized by low-frequency emphasis. An attenuation cover configured for desirable performance in such a scene acts as a high-pass attenuator to reduce the low-frequency input to the microphone. FIG. **7**B is a schematic graph depicting an unmodified acoustic stimulus and a modified or attenuated acoustic stimulus resulting from use of such a high-pass attenuation cover. When the auditory scene is classified as wind or noise that is above the input dynamic range, the auditory prosthesis will prompt or notify the recipient to apply an attenuation cover optimized for such an environment. The use of this type of attenuation cover can also be combined with further signal processing after the input stage (e.g., noise reduction). Thus, the technologies described herein pair scene classification with utilization of recipient-applied attenuation covers.

FIG. **8** is a graphical representation of an attenuation level determination algorithm, initially described above as one method of determining whether distortion has exceeded a predetermined threshold. Here, statistics of an output signal from an analog-to-digital converter are monitored on an ongoing basis. The sound processing components or a discrete distortion detection module can estimate the peak level of distortion and send a notification to a recipient when a cover is recommended or desirable. Additionally, based on a quantification of the level of distortion, the distortion detection module can recommend an attenuation cover based on a degree of attenuation required to avoid clipping of the output signal. The algorithm can determine the ratio of samples in a given time interval that are clipped so as to estimate how far the acoustic signal is above the full-scale value of the analog-to-digital converter. Example data for maximum clipping with a sliding 8 ms time window is shown in FIG. **8** for an example music input signal. As the percentage of samples clipped during the time window increases, the algorithm determines that more attenuation is needed. Once the attenuator cover having known attenuation characteristics is installed or applied, the distortion detection module can similarly track the peak level. When the peak level falls below the digital full scale value by more than the attenuation of the cover, the recipient can be notified to remove the attenuation cover.

FIG. **9** illustrates one example of a suitable operating environment **700** in which one or more of the present embodiments can be implemented. This is only one example of a suitable operating environment and is not intended to suggest any limitation as to the scope of use or functionality. One such operating environment **700** can be the sound processor and related modules of an auditory prosthesis.

In its most basic configuration, operating environment **700** typically includes at least one processing unit **702** and memory **704**. Depending on the exact configuration and type of computing device, memory **704** (storing, among other things, instructions to detect distortion and identify attenuation covers as described herein) can be volatile (such as RAM), non-volatile (such as ROM, flash memory, etc.), or some combination of the two. This most basic configuration is illustrated in FIG. **9** by line **706**. Further, environment **700** can also include storage devices (removable, **708**, and/or non-removable, **710**). In the context of an auditory prosthesis, removable storage devices **708** can be connected, e.g., to the prosthesis via an auxiliary port. Similarly, environment **700** can also have input device(s) **714** such as touch screens, buttons or switches, microphones for voice input, etc.; and/or output device(s) **716** such as a display, indicator button stimulator unit for delivery of stimulus to a recipient, etc. Also included in the environment can be one or more communication connections, **712**, such Bluetooth, RF, etc.

Operating environment **700** can include at least some form of computer readable media. Computer readable media can be any available media that can be accessed by processing unit **702** or other devices comprising the operating environment. By way of example, and not limitation, computer readable media can comprise computer storage media and communication media. Computer storage media includes volatile and nonvolatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Removable media can be connected to the auditory prosthesis via an auxiliary port. Such media is also referred to herein as "connectable media." Examples of removable (connectable) and non-removable computer storage media include, RAM, ROM, EEPROM, flash memory or other memory technology, CD-ROM, digital versatile disks (DVD) or other optical storage, magnetic cassettes, magnetic tape, magnetic disk storage or other magnetic storage devices, solid state storage, or any other non-transitory medium which can be used to store the desired information. Communication media embodies computer readable instructions, data structures, program modules, or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery media. The term "modulated data signal" means a signal that has one or more of its characteristics set or changed in such a manner as to encode information in the signal. By way of example, and not limitation, communication media includes wired media such as a wired network or direct-wired connection, and wireless media such as acoustic, RF, infrared and other wireless media. Combinations of any of the above should also be included within the scope of computer readable media.

The operating environment **700** can be a single auditory prosthesis operating alone or in a networked environment using logical connections to one or more remote devices. The remote device can be, in certain examples, a smartphone, tablet, personal computer, a server, or laptop.

In some aspects, the components described herein comprise such modules or instructions executable by computer system **700** that can be stored on computer storage medium and other tangible mediums and transmitted in communication media. Computer storage media includes volatile and non-volatile, removable (connectable) and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules, or other data. Combinations of any of the above should also be included within the scope of readable media.

The attenuation covers described herein can be manufactured of metals such as titanium, aluminum, stainless steel, etc. Additionally, covers can be manufactured from fiber compound filters. Such filters are incorporated into the Musicians Earplugs™, available from Etymotic Research, Inc., of Elk Grove Village, Ill. Similar materials displaying attenuation characteristics desirable in the described systems and methods are utilized in the DefendEar™ line of products manufactured by Westone Laboratories, Inc., of Colorado Springs, Colo. Other acceptable materials include expanded polytetrafluoroethylene (ePTFE) utilized in Gore™ Acoustic Vents, available from W. L. Gore & Associates, Inc., of Elkton, Md. Porous plastics, glass fibers, and polymer fibers available from Porex Corporation, of Fairburn, Ga., can be utilized. Additionally, SaatiTech fabrics, manufactured by Saati Americas of Somers, N.Y., can be utilized. Attenuation covers can be coated with one or more films or coatings to improve performance or increase operable life. Hydrophobic coatings can be particularly desirable, as are coatings that increase UV light resistance to prevent degradation of the covers. Known injection molding and machining processes can be utilized. The covers can be a unitary structure or can be manufactured in multiple pieces that can be joined together with an appropriate adhesive.

This disclosure described some embodiments of the present technology with reference to the accompanying drawings, in which only some of the possible embodiments were shown. Other aspects can, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein. Rather, these embodiments were provided so that this disclosure was thorough and complete and fully conveyed the scope of the possible embodiments to those skilled in the art.

Although specific aspects are described herein, the scope of the technology is not limited to those specific embodiments. One skilled in the art will recognize other embodiments or improvements that are within the scope of the present technology. Therefore, the specific structure, acts, or media are disclosed only as illustrative embodiments. The scope of the technology is defined by the following claims and any equivalents therein.

What is claimed is:

1. A method comprising:
- receiving a sound input at an auditory prosthesis;
- converting the sound input to a digital signal;
- detecting a distortion level of the digital signal, wherein the distortion level represents distortion in excess of a threshold;
- selecting an attenuation cover based on the distortion level, wherein the cover is selected to reduce distortion to a level less than the threshold;
- sending a notification of the selected cover to a recipient; and
- physically receiving the attenuation cover at the auditory prosthesis, thereby forming an attachment between the cover and the auditory prosthesis.

2. The method of claim **1**, wherein the converting operation comprises passing the sound input through an analog-to-digital converter.

3. The method of claim **1**, wherein the sending operation comprises terminating a stimulus signal to the recipient.

4. The method of claim **1**, wherein the notification comprises a tone distinct from the digital signal.

5. The method of claim **2**, wherein the notification comprises a signal sent to a device remote from a device containing the analog-to-digital converter.

6. The method of claim **1**, further comprising quantifying the distortion of the digital signal.

7. The method of claim **6**, wherein the notification is based at least in part on the quantifying operation.

8. The method of claim **1**, further comprising:
- receiving an engagement signal; and
- sending a confirmation signal to the recipient.

9. A method comprising:
- receiving a sound input at an auditory prosthesis;
- converting the sound input to a digital signal;
- quantifying a distortion of the digital signal;
- selecting an attenuation cover based on the distortion and an attenuation characteristic of the cover;
- sending a notification to a recipient; and
- engaging with the attenuation cover, thereby attaching the attenuation cover and the auditory prosthesis.

10. The method of claim **9**, wherein the cover is selected to reduce the distortion to less than a predetermined threshold.

11. The method of claim **9**, wherein the identifying operation comprises selecting the cover from a plurality of covers wherein each cover of the plurality of covers comprises a known attenuation characteristic.

12. The method of claim **11**, wherein the quantifying operation comprises:
- determining a distortion in excess of a predetermined threshold; and
- wherein the identifying operation comprises:
  - selecting the cover based on a minimum attenuation required to reduce the distortion to less than the predetermined threshold.

13. The method of claim **12**, wherein the predetermined threshold is based at least in part on a sound pressure level.

14. The method of claim **12**, wherein the predetermined threshold is based at least in part on a number of distorted digital signal samples.

15. The method of claim **11**, wherein the notification comprises an indication of the selected cover.

16. The method of claim **9**, wherein the notification comprises a tone distinct from the digital signal.

17. A method comprising:
obtaining a digital signal associated with a sound input at an auditory prosthesis;
determining a distortion of the digital signal in excess of a predetermined threshold;
selecting an attenuation cover based on the cover having an attenuation characteristic that reduces the distortion to less than the predetermined threshold;
sending a notification to a recipient; and
securing the attenuation cover by the auditory prosthesis.

18. The method of claim 17, wherein the predetermined threshold is based at least in part on a sound pressure level.

19. The method of claim 17, wherein the predetermined threshold is based at least in part on a number of distorted digital signal samples.

20. The method of claim 17, wherein the notification comprises an indication of the selected cover.

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